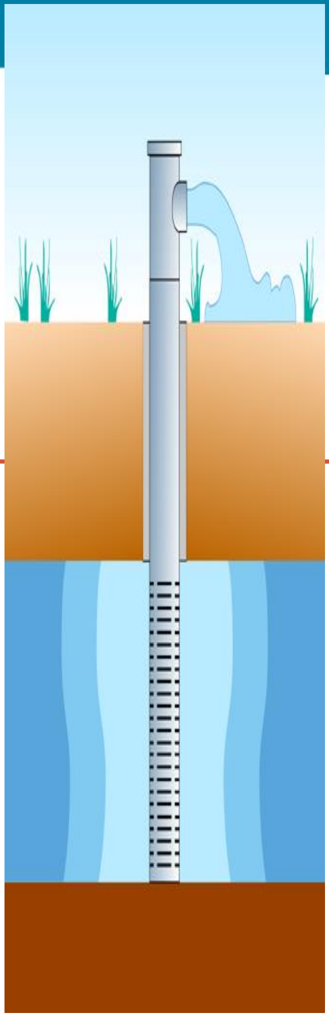


CITY OF VICTORIA, TEXAS AQUIFER STORAGE RECOVERY WELL ASR-19

OPERATIONS & MAINTENANCE TRAINING SESSION

Introduction to ASR

R. David G. Pyne, P.E. and Ted Belser, P.E.
ASR Systems LLC
Gainesville, Florida

May 8, 2018

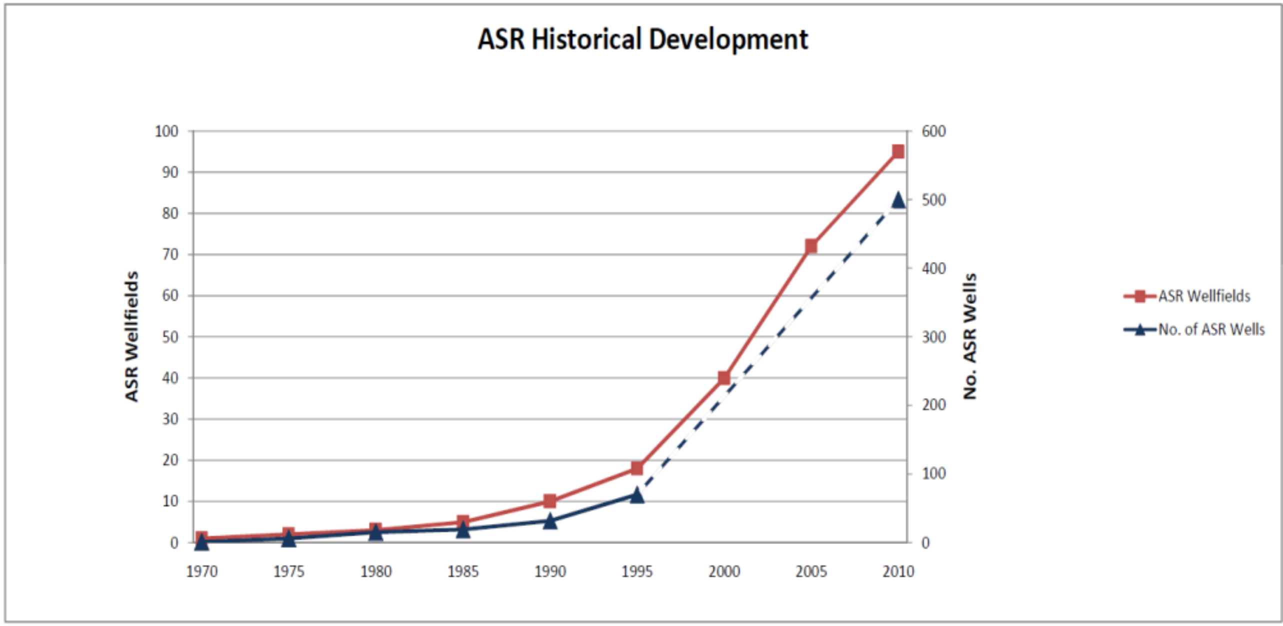
Global implementation of ASR since 1985 to achieve water supply sustainability and reliability

- Australia
- India
- Israel
- Canada
- England
- Netherlands
- South Africa
- Namibia
- United Arab Emirates
- Bangladesh
- And others in development (Kuwait, Taiwan, Indonesia, Qatar, Serbia, China, Oman)

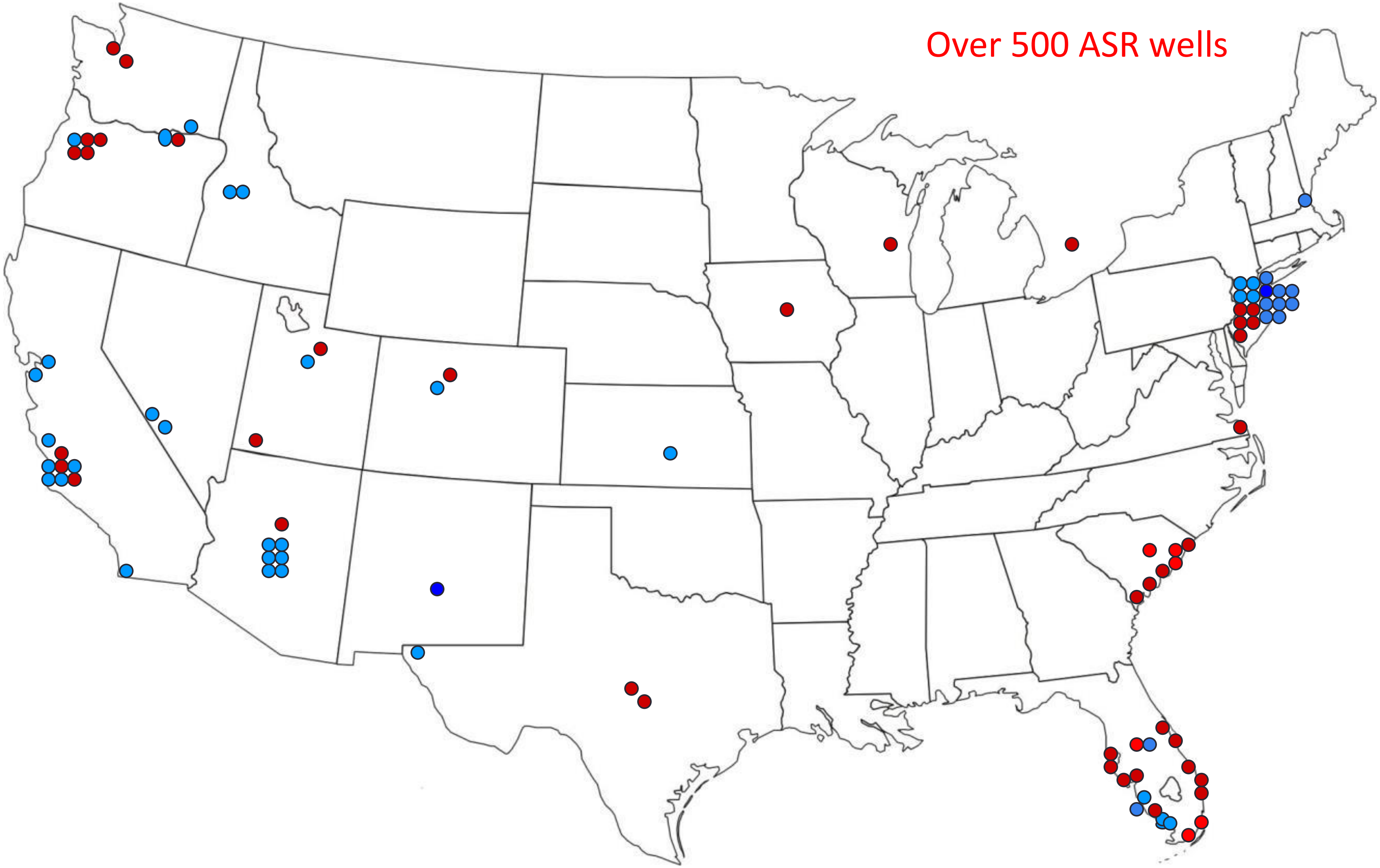
Adelaide, Australia ASR Well

ASR Development in the U.S. has been rapid during the past twenty years

- 29 different ASR applications
- Many different types of water sources for aquifer recharge
- Storage in many different types of aquifers and lithologic settings



At least 120 Operational ASR Wellfields in the United States (2012)



Texas ASR Experience

- Operational ASR Wellfields
  - El Paso Water Utilities
  - City of Kerrville
  - San Antonio Water System
- ASR Wellfields in Development
  - City of Victoria
  - New Braunfels Utilities
  - City of Corpus Christi
  - City of Buda
- ASR Feasibility studies underway or completed
  - Barton Springs, Port Lavaca, Laredo, Lubbock, GBRA, HGSD
  - Several others

A broad range of water sources and storage zones is utilized for ASR

- Water sources for ASR storage
  - Drinking water
  - Reclaimed water (AZ, TX, FL, NJ, CA)
  - Seasonally-available stormwater
  - Groundwater from overlying, underlying or nearby aquifers
- Storage zones
  - Fresh, brackish and saline aquifers
  - Confined, semi-confined and unconfined aquifers
  - Sand, clayey sand, gravel, sandstone, limestone, dolomite, basalt, conglomerates, glacial deposits
  - Vertical "stacking" of storage zones

Chandler, AZ

Tumbleweed ASR Wellfield

Storing Reclaimed Water for Aquifer Recharge

ASR Operating Ranges

- Well depths
  - 30 to 3,000 feet
- Storage interval thickness
  - 20 to 400 feet
- Storage zone Total Dissolved Solids
  - 30 mg/L to 39,000 mg/L
- Storage Volumes
  - 100 AF to 60,000 AF
  - (30 MG to 20 BG)
- Bubble radius usually less than 1000 ft
- Individual wells up to 8 MGD capacity
- Wellfield capacity up to 157 MGD

Calleguas MWD, California

ASR Well

ASR has many applications to meet local needs

- **Seasonal storage**
- **Peak, diurnal and emergency water needs**
- **Water banking, or long term storage**
- Restore groundwater levels
- Reduce subsidence
- **Maintain distribution system flows and pressures**
- **Improve water quality**
- Prevent seawater intrusion
- Protect endangered species
- Agricultural water supply
- Temperature control
- Hydraulic control of contaminant plumes
- Defer expansion of water facilities
- **Disinfection Byproduct reduction**
- ….several other applications to date
- ….29 different applications to date

Kiawah Island, South Carolina, ASR-2

Identifying and prioritizing these applications is a logical first step in ASR planning

Several factors have contributed to ASR global implementation

- Economics
  - Typically less than half the capital cost of alternative water supply sources
  - Phased implementation
  - Marginal cost pricing
- Proven Success
  - About 120 wellfields in over 20 states with over 500 operating, fully permitted ASR wells
- Environmental and Water Quality Benefits
  - Maintain minimum flows
  - Small storage footprint compared to surface reservoirs
- Adaptability to Different Situations
  - Fresh, brackish or saline storage aquifers
  - Drinking water, reclaimed water, stormwater or groundwater storage
  - Over 29 different applications

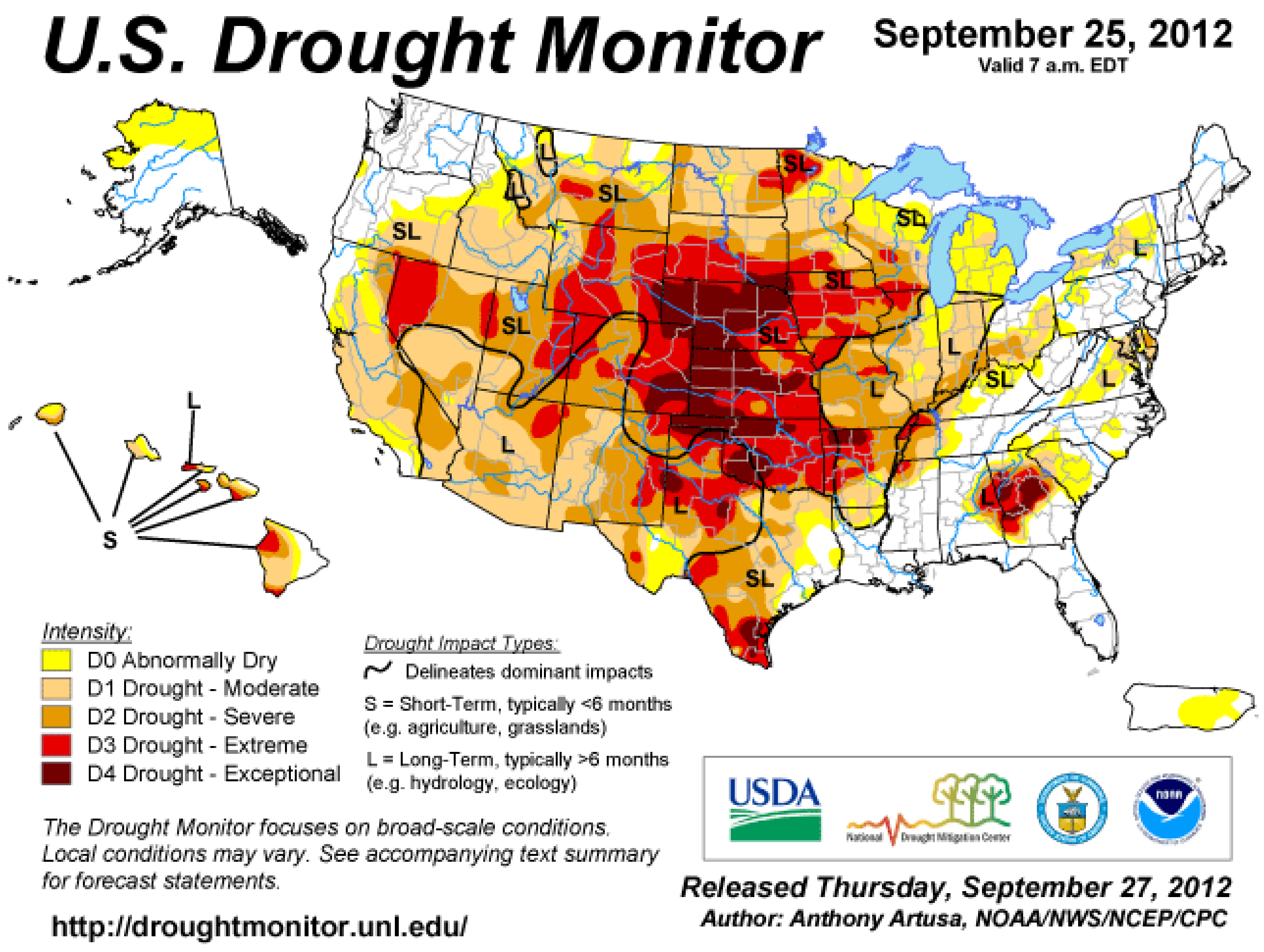
Mt Pleasant, SC – Well ASR-2

Three case studies illustrate the range of applications for ASR to meet end-user needs

- San Antonio, Texas
- Orangeburg, South Carolina
- Hilton Head, South Carolina

Highlands Ranch, CO
One of 26 ASR wells underground in vaults, storing drinking water to help meet peak summer demands

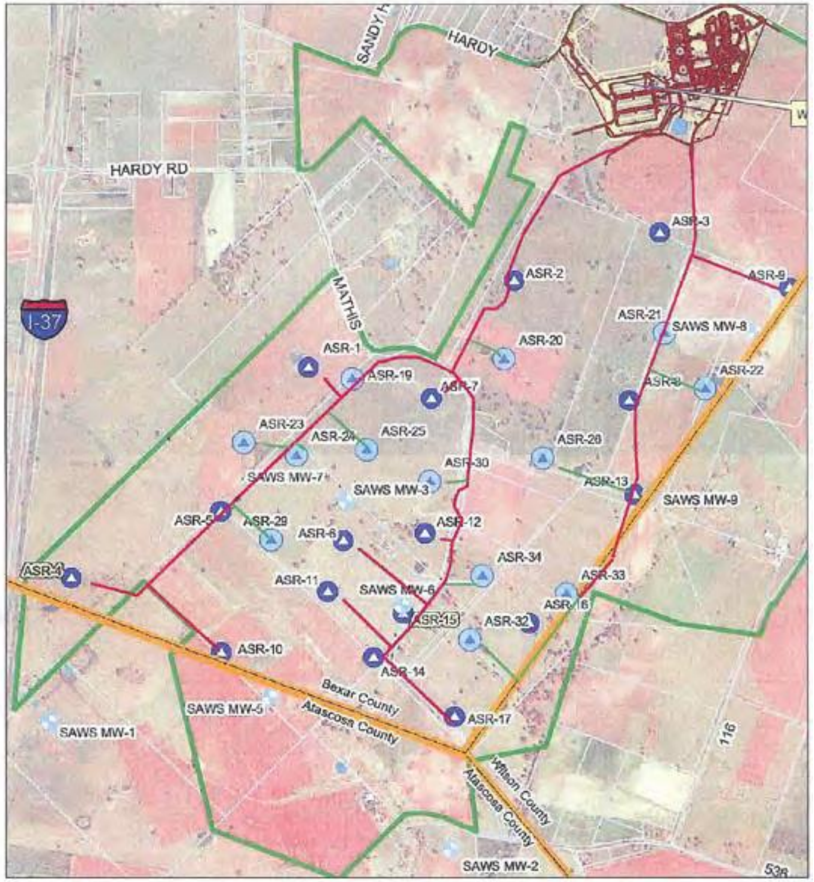
Severe to Extreme Drought Affected 40% of the U.S. as of 8/31/12



San Antonio Water System, Texas

- Twin Oaks WTP and ASR wellfield
- Wellfield area is 3,200 acres
- 29 ASR wells and 3 production wells
- 1,800 to 2,500 gpm/well
- Total recovery capacity – 60 mgd
- Third largest ASR wellfield in U.S.
- Carrizo-Wilcox is a semi-confined sand aquifer
- Began recharge in 2004; up to about 100,000 AF stored to date
- Total construction cost: $238M
  ASR wellfield cost: $52M
  ASR unit capital cost:

US$0.87/gpd recovery capacity



SAWS ASR Wellfield, 2005

San Antonio Water System (SAWS)

- ASR objectives are long term storage to meet the “Drought of Record” and providing emergency water supplies
- During the 2010-2011 extreme drought the SAWS ASR wellfield produced 40 mgd to augment local water supplies for several months, relieving pressure on groundwater withdrawals from the Edwards Aquifer which supplies Comal and San Marcos Springs, plus all local water supplies

SAWS Flow Control Facilities and Ground Storage Reservoir at Twin Oaks WTP and ASR Wellfield

San Antonio Water System ASR

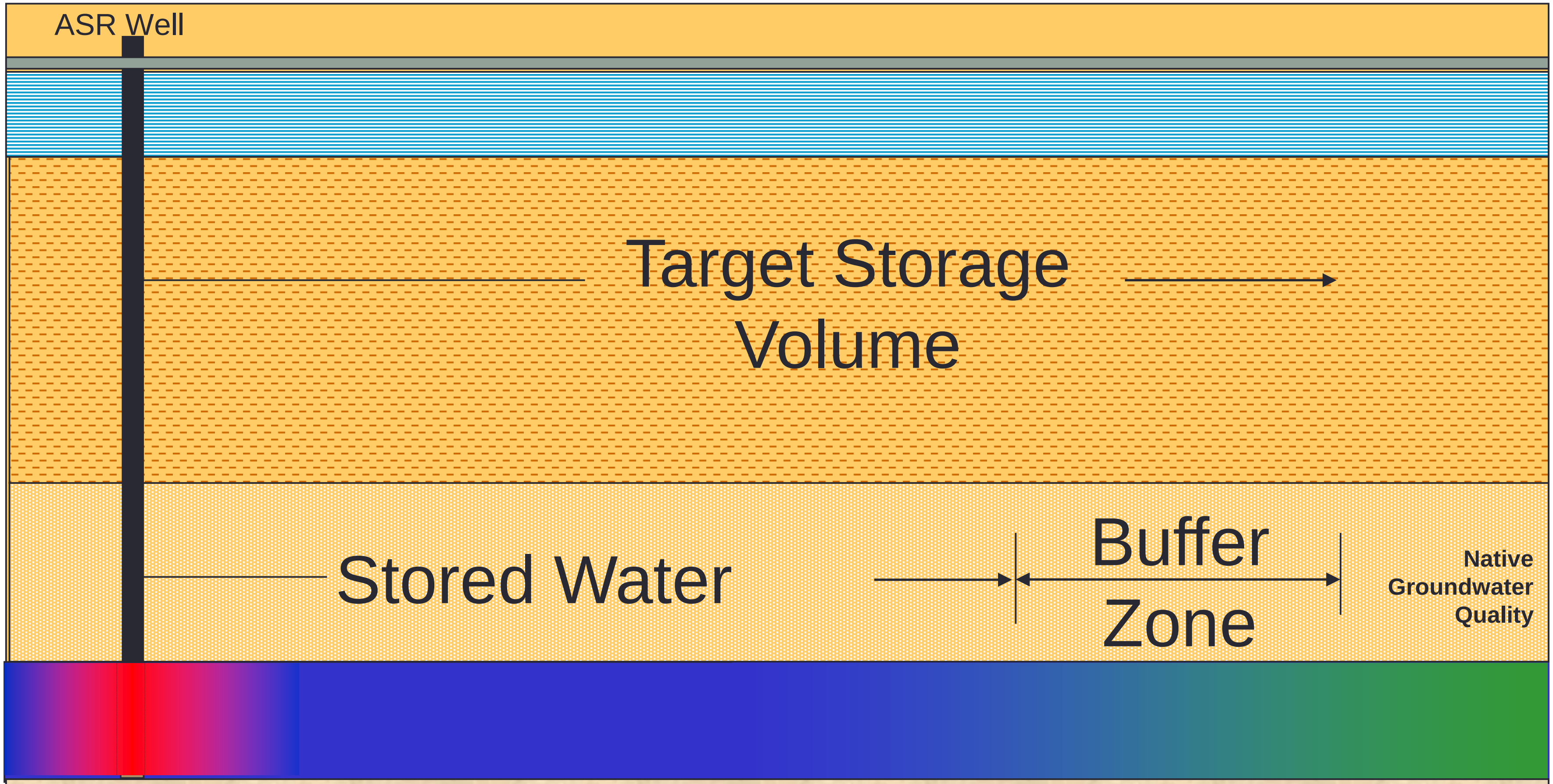
- Water recovered from ASR wells normally does not require retreatment other than disinfection
- Water pumped from the three production wells requires full treatment for Fe and Mn removal, plus disinfection
- Toward the end of the drought ASR recovered water required treatment for Fe and Mn removal, due to blending with ambient groundwater

SAWS Twin Oaks Water Treatment Plant at the ASR Wellfield, 2006

SAWS ASR: Lessons Learned

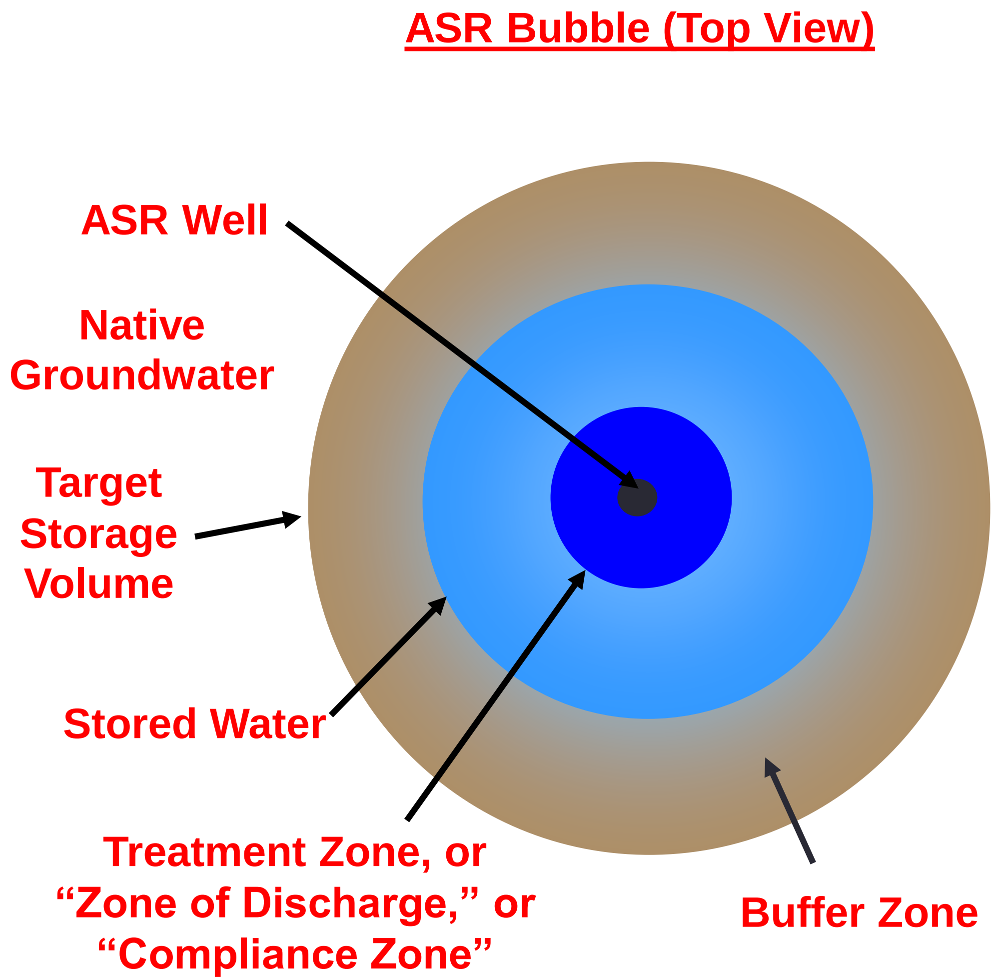
- Successful performance during the extreme drought a few years ago received enthusiastic local support and was noted by water managers statewide, galvanizing interest in ASR in Texas
- Mitigation plan has been effective for dealing with perceived offsite adverse impacts upon wells and groundwater levels
- An operating plan is needed to guide decisions regarding when to start and stop recharge and recovery; when is the “tank” full, etc.
- Legislation and rule-making has boosted interest in ASR development in Texas by addressing governance constraints.

Target Storage Volume



Recovery efficiency is defined as volume recovered as percentage of volume stored in any given operating cycle, meeting established water quality criteria.

In addition to water storage, treatment occurs in an aquifer due to natural processes.



- NO_3, NH_3, P
- THMs
- HAAs
- H_2S
- Fe, Mn, As
- Gross Alpha Rad.
- Bacteria
- Protozoa
- Viruses

Other ASR Issues for Consideration

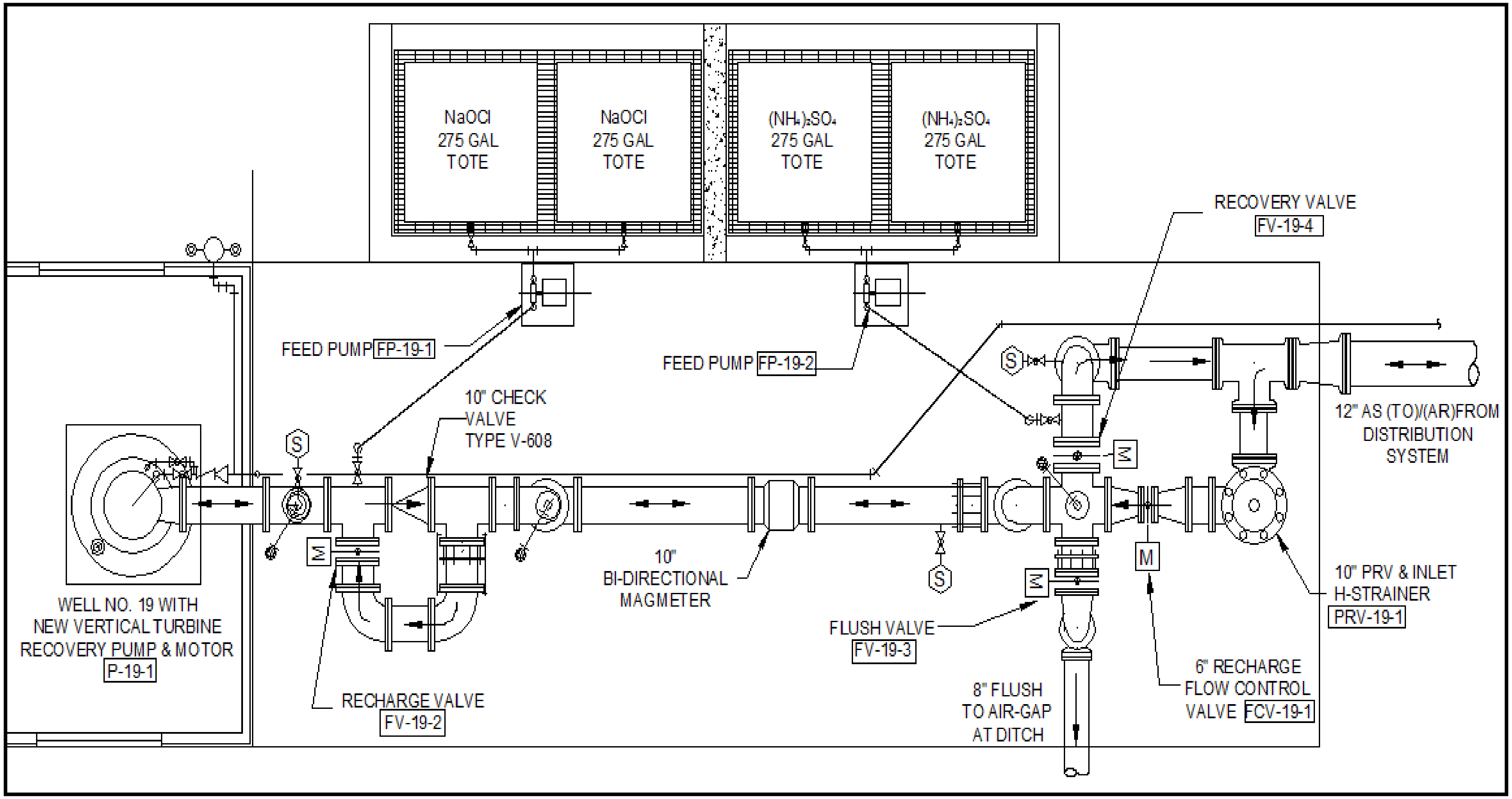
- Interim Recharge
- Trickle flow
- Wellhead Pressure (pump column, casing annulus)
- Backflushing w/ VFD (frequency, procedures)
- Radial Injection Surge Development (RISD)
- Recharge flow rate variability
- Recovery flow rate variability
- Water level variability
- Water level and pressure measurement
- Lateral velocity of stored water movement
- Recovery efficiency
- Tracer testing
- Monitor well utilization (cycle testing; long term)
- Historian and manual data collection and reporting

Well ASR 19

- Constructed 1970; rehabilitated 1992, 2017
- 18-inch carbon steel casing to 400 ft
- Bottom hole depth 1,068 ft
- Pump set at 375 ft; design yield is 1,500 gpm
- Screened in Evangeline aquifer (clay, sand, gravel)
- 10-inch pipe-based, wire-wrap screens
  - Total length 270 ft; effective length 82 ft
  - 460 to 510 ft effective
  - 544 to 594 ft effective
  - 642 to 694 ft
  - 780 to 804 ft
  - 852 to 904 ft
  - 988 to 1,008 ft
  - 1,026 to 1,048 ft

Video Log:
Pipe base at 587 ft has corroded and/or eroded, and is missing, exposing screen

ASR Well 19 Piping Diagram



Operations Manual, p. 3

Sampling and Water Level Measurement

Water Level
Transducer, ASR-30

Water Level & Sampling for
Monitor Well 21

Well ASR-30
Wellhead Facilities

View at Well End of
Wellhead Piping

View at Strainer/PRV
End of Wellhead Piping

Air Release Valves

The Problem of Air Entrainment During Recharge of ASR Well

Downhole Velocity
V < 1 ft/sec

No Problem

If downward velocity is <u>less than 1 ft/sec</u> the air bubbles will rise to the top and be vented from the well.

Downhole Velocity
V > 1 ft/sec

Air Entrainment Problem

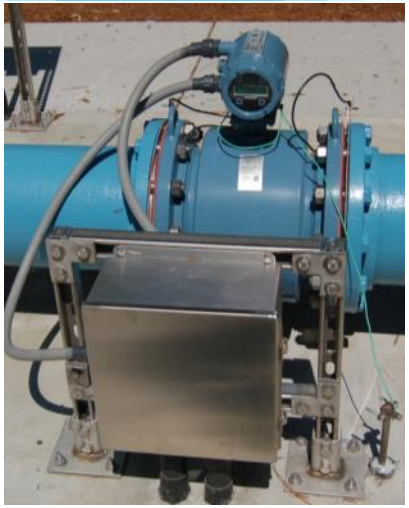
If downward velocity is <u>more than 1 ft/sec</u> the air bubbles will be carried down the well casing and into the formation of the aquifer.

Disinfection Equipment

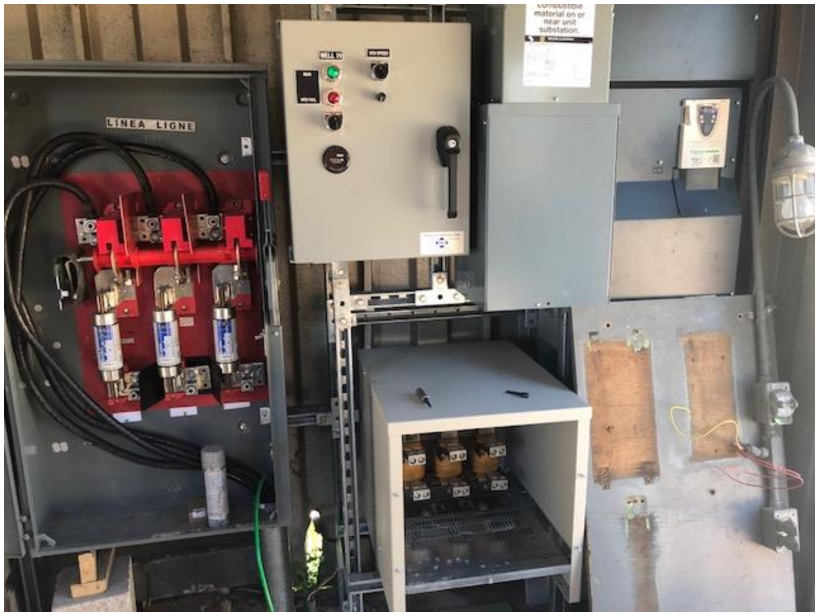
NaOCl and LAS
Storage Tanks and
Feed Pumps

Chlorine Residual Analyzer

Field Instruments:
Pressure, Flowrate, Level



Electrical System Panels

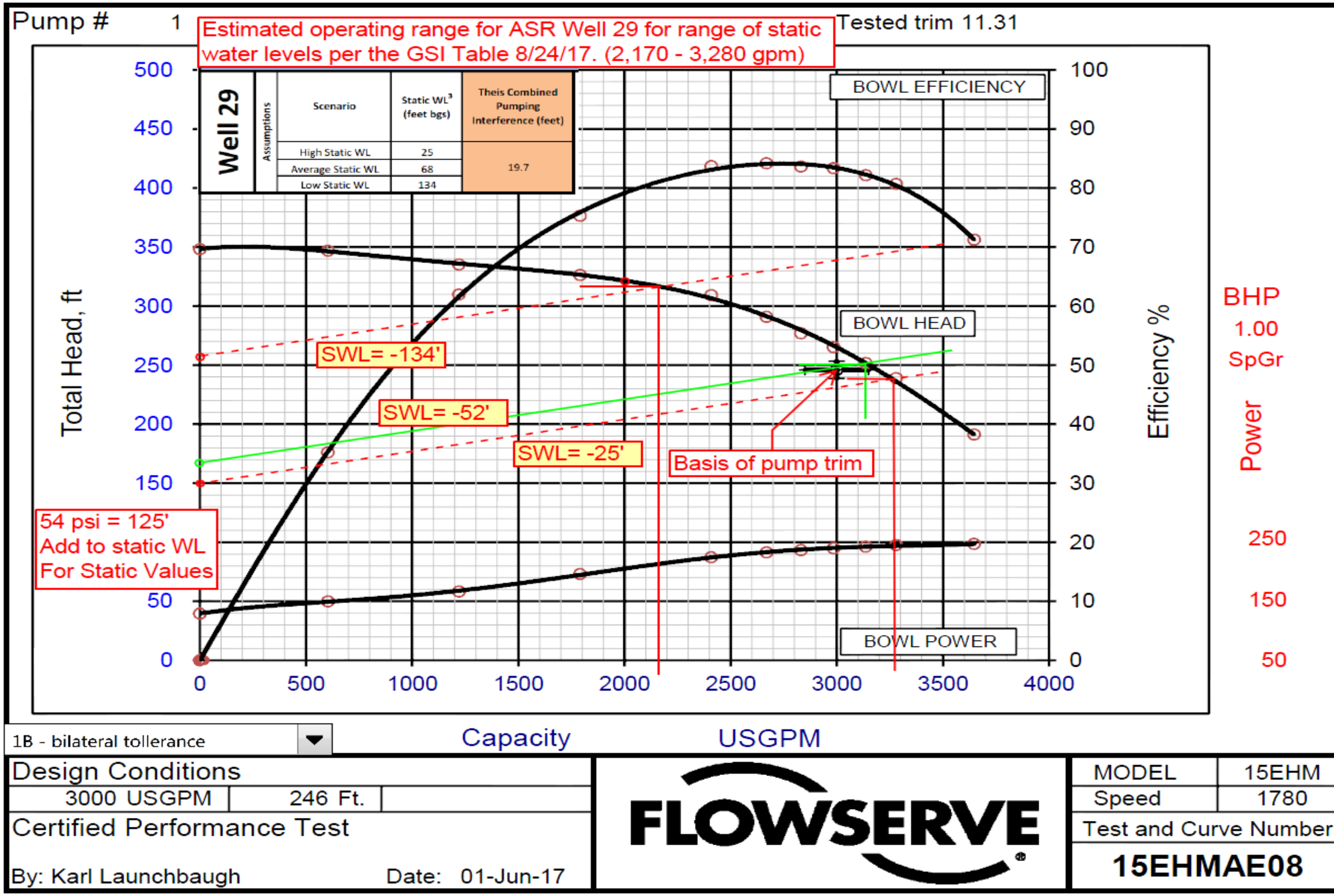


Recovery Pump
Adjustable Frequency Drive

Motor Control Center

Flushing System Air-Gap Discharge

Well ASR-29 Recovery Pump Curve



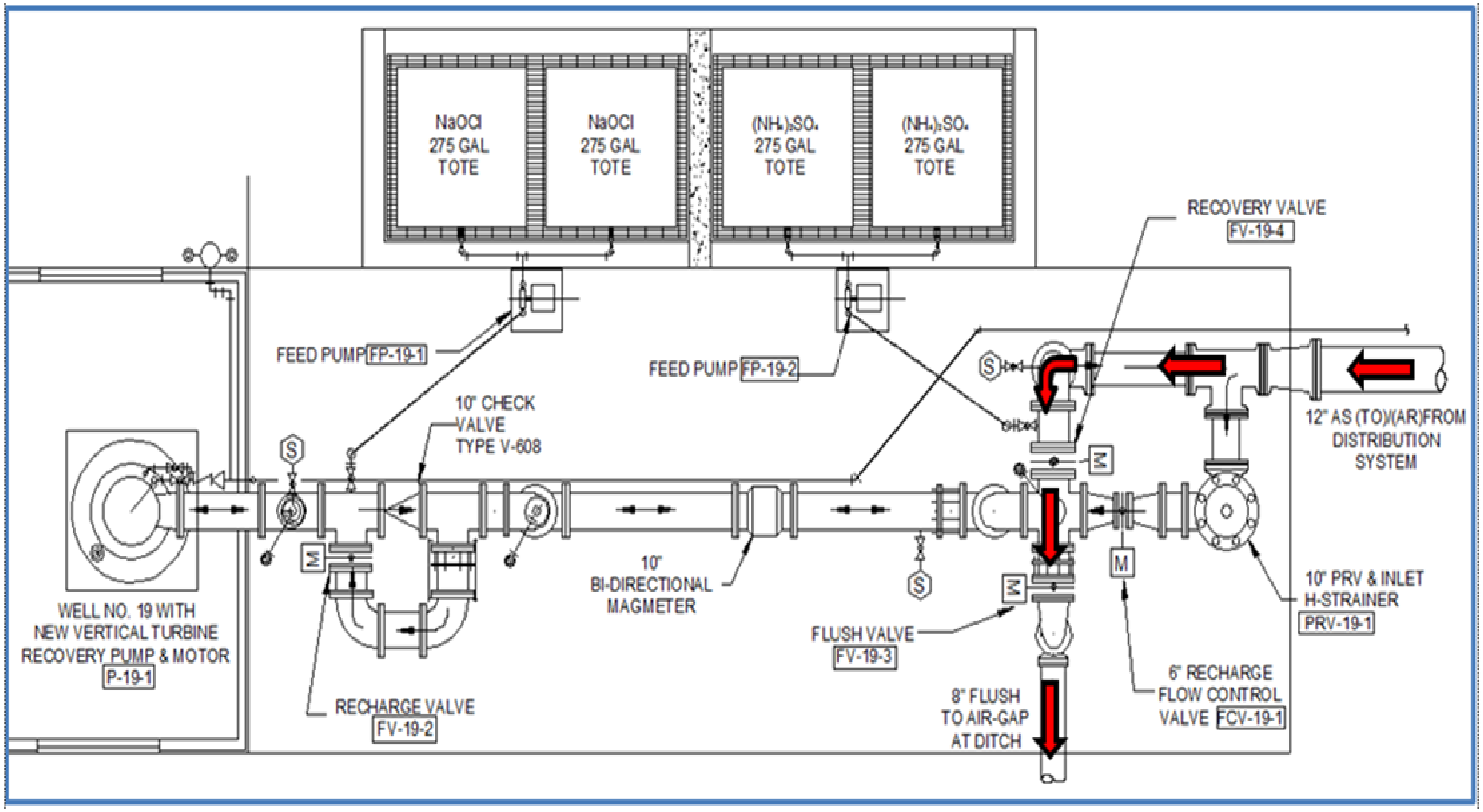
Pump & Valve Status for Various Modes of Operation

Tag No.	Item	Recharge	Storage/TF	Flush	Recovery
PRV-19-1	Pressure Reducing Valve	Operating	N/A	N/A	N/A
FCV-19-1	Recharge Flow Control Valve	Manual Modulation	Closed	Closed	Closed
FV-19-2	Column Recharge Valve	Open*	Closed	Closed	Closed
FV-19-3	Flushing Valve	Closed	Closed	Open	Closed
FV-19-4	Recovery Valve	Closed	Closed	Closed	Open
P-19-1	ASR Pump	Off	Off	On - AFD	On - AFD
FP-19-1	NaOCl Pump	Off	Off	Off	On
FP-19-2	LAS Pump	Off	Off	Off	On

Exhibit 2 – Equipment Status Summary

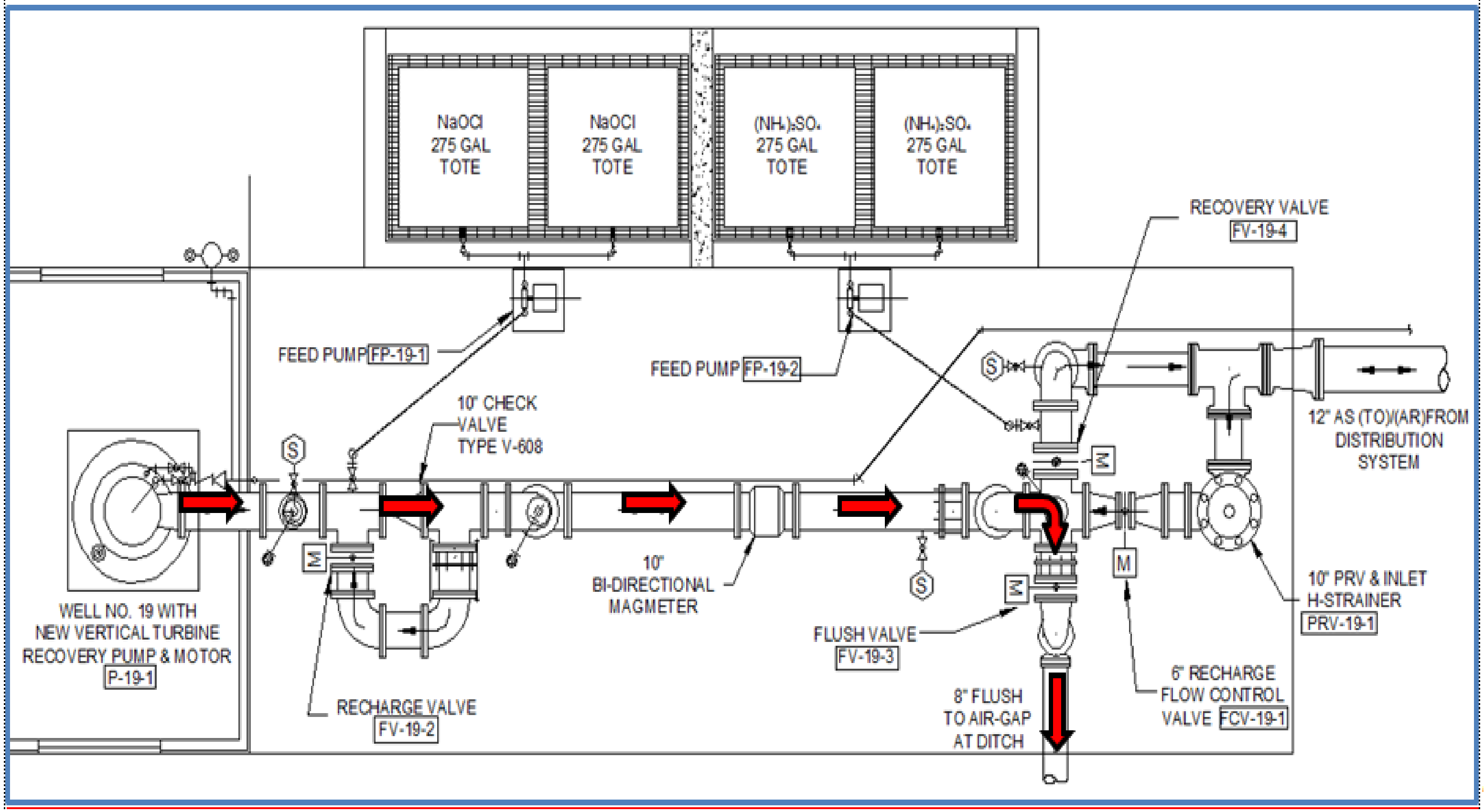
* Open only after purging air from wellhead piping by manual control of FCV-19-1.

Manual Flush: Recharge Path from Distribution System



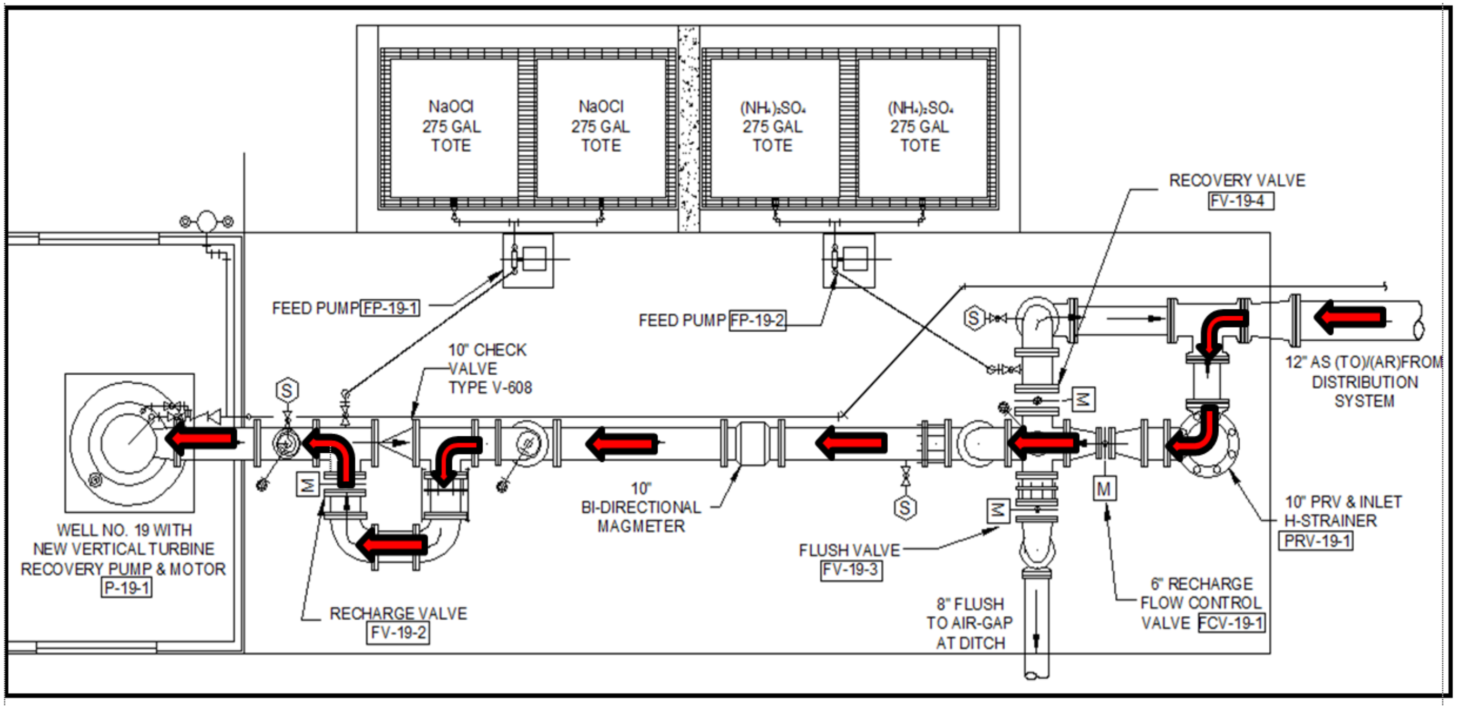
See Exhibit 4 on p. 7

Operating Mode: Manual Backflush of Well



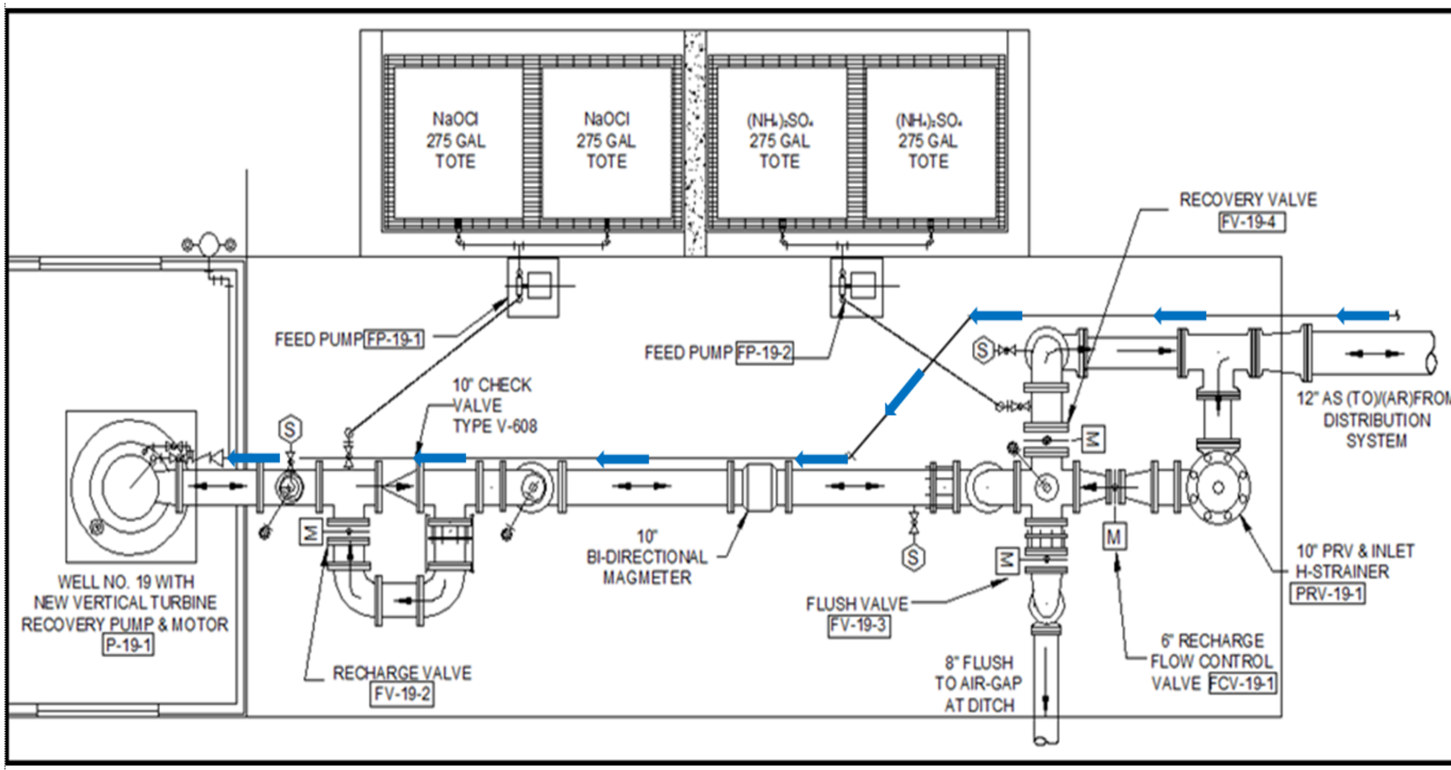
See Exhibit 3 on p. 5

Recharge of Water from Distribution System



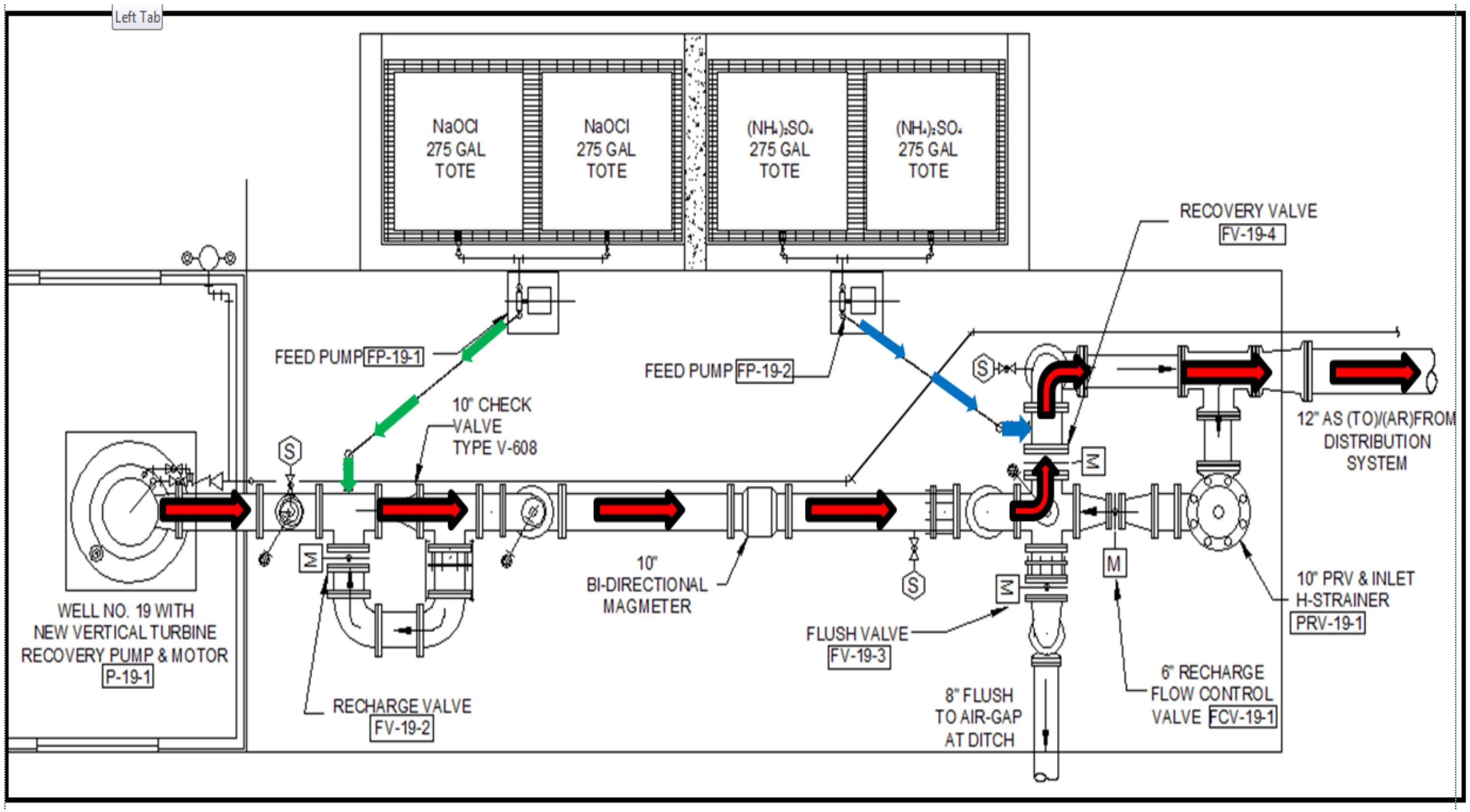
See Exhibit 5 on p. 8

Storage and Trickle Flow



See Exhibit 6 on p. 10

Recovery to Distribution System



See Exhibit 7 on p. 11

Cycle Testing Program

ASR Cycle Testing Plan								
City of Woodland Well ASR-29								
November 2017 to September 2019								
Activity	**Approximate Duration (days)**				**Estimated Volume (MG)**			**Comments**
	Recharge	Storage	Recovery	Cumulative	Recharge	Recovery	Cumulative	
Cycle Test One	60	2	5	67	120	15	105	November 2017 to February 2018
Cycle Test Two	70	60	35	165	140	105	140	March 2018 to September 2018
Cycle Three	180	60	100		360	300	200	October 2018 to September 2019

Notes:

1. Assumes average recharge flow rate of 2.0 MGD, varying between 1.5 and 2.5 MGD
2. Assumes recovery flow rate averaging 3.0 MGD, varying between 2.5 and 3.5 MGD
3. Assumes Cycle One occurs during November 2017 to February 2018 with recovery to waste
4. Assumes Cycles 2 and 3 recover water to the distribution system
5. Flow rates, durations and volumes will vary to match operational needs, constraints and opportunities
6. Assumed Target Storage Volume is 500 MG, of which 324 MG is available for recovery and 176 MG is buffer zone

Cycle One

- Performance Testing (See p.5 – 12 of Operations Manual)
- Startup (See p. 20-23 of Operations Manual)
- Duration: April 2018 to December 2018 (tentative)
  - Recharge April to mid-October (about six months)
  - Storage period (about two weeks)
  - Recovery period (about one month)
  - Resume recharge for Summer 2019 (at option of City)
- Recharge rate 350 to 500 gpm (estimated)
- Recovery rate 1,500 gpm (design, adjustable)
  - Recover half of cumulative stored water volume, forming buffer zone
- August 2018 pause to confirm recovered water quality
  - Stop recharge for one week
  - Pump out 2 to 4 MG and get sample for PDWS and SDWS analysis
  - Resume recharge

Cycle Testing Monitoring Program

- See Operations Manual (pages 6-9, 6-10)
- List A constituents: beginning, end of recharge and monthly in between at Well 19 (about 6 samples)
- List B constituents from Well 19 at beginning, middle and end of recovery (3 samples)
- List C constituents from Well 19 at end of recovery (repeat complete Appendix A baseline analysis – 1 sample)
- List D constituents from Well 21 at beginning, middle, end of recharge into Well 19 (about six samples)

  plus
- Data Collection Form (Appendix B) (flows, levels, volumes, pressures, field water quality constituents)

Appendix C – Permits and Authorizations

- TCEQ Construction Permit
- TCEQ Underground Injection Control (UIC) authorization for Class V Experimental Well
- UIC permit application pending upon completion of cycle testing, 2019

ASR Book, Second Edition

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